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PRELIMINARY EVALUATION OF NORSAR

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PRELIMINARY EVALUATION OF NORSAR

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ABSTRACT

A preliminary evaluation of NORSAR, using short-period data from one noise sample and two teleseismic events, was performed to determine: 1) the minimum inter-sensor spacing required to produce optimum rms noise reduction by summing, and 2) the amount of signal loss, rms noise reduction and signal-to-noise gain produced by beamforming the array.

Results show that the minimum inter-sensor spacing required to achieve rms noise reduction equivalent to $N^{\frac{1}{2}}$ after prefiltering and summing is approximately three kilometers.

The evaluation also shows that prefiltering the data, using the Fc filter (0.7 - 5.0 cps), and beamforming the array by time-shifting, using only computed travel-time differences, produces a signal loss of less than one db on the beamed output, a rms noise reduction equivalent to $N^{\frac{1}{2}}$, and a signal-to-noise ratio improvement which is attenuated only one db relative to $N^{\frac{1}{2}}$.

Analysis of the noise power spectra performed on 100 second noise samples also confirms that, when the minimum intersensor spacing is greater than three kilometers, the noise attenuation at 1 cps produced by summing the array is equivalent to a factor of $N^{\frac{1}{2}}$.

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INTRODUCTION AND PURPOSE

The purpose of this report is to present a preliminary evaluation of the Norwegian Seismic Array (NORSAR). We are interested, specifically, in determining: 1) the minimum inter-sensor spacing required to produce optimum rms noise reduction by summing the array, and 2) the amount of signal loss, rms noise reduction, and signal-to-noise gain produced by beamforming the array. The basic procedures include re-formating the original data, prefiltering, computing power spectra, time-shifting, and summing.

The original data are short-period seismograms recorded at NORSAR. They include one signal-free noise sample recorded on 29 December 1967, one teleseismic event recorded on 4 February 1968, and a second teleseismic event recorded on 11 February 1968.

The configuration of the NORSAR subarrays which recorded the data used in this study is shown in Figure 1. The digital programs which are used in this evaluation are described in SDL Report No. 216 (Clark, 1968).

PROCEDURE

Each seismogram used in this study was recorded at the site on Astrodata tape. The digital seismograms were recorded on 7-track magnetic tape in multiplex form at the rate of 800 bpi with odd parity. Sine wave calibrations (1 cps) were performed on each data channel.

Selected portions of the multiplexed data were demultiplexed and converted to SDL library tape format. For the noise sample the selected portion of data consists of three minutes of signal-free noise. For each of the two teleseismic events the selected data consist of two minutes of noise and one minute of signal. The sine wave calibration data were also demultiplexed and converted to SDL library format. For the noise sample, the calibration data were taken from 28 December 1967; for the two teleseismic events, the calibration data were taken from 11 February 1968.

The converted data were detrended to remove the mean, demagnified (using the corresponding calibration data described above) to convert digital counts to equivalent earth motion in millimicrons at 1 cps, and prefiltered to the band 0.7 - 5.0 cps, i.e., the Fc filter.

For the noise sample, the amount of rms noise amplitude reduction produced by summing various combinations of the NORSAR subarrays was computed. Each subarray combination was selected to give a particular average inter-sensor spacing. The combinations used and the corresponding inter-sensor spacings are given in Table 1. The rms noise amplitude is defined as the root-mean-square value obtained in a 100-second window. The rms noise amplitude reduction, in decibels, was computed from the following formula:

$$db = 20 \log \left[\frac{\text{value on unphased sum}}{\text{mean value of input channels}} \right]$$

The noise power spectra were computed using a digital program based on the Blackman and Tukey method. The spectral analysis was performed on the same 100 seconds of the noise sample from the individual subarrays and from the unphased sums of the five subarray combinations described above. The plot of the noise power spectra from each unphased sum was then compared with the plot of the average of the spectra from the individual subarrays included in that particular sum.

Beams were formed by time-shifting the subarray data to align P-arrivals by applying travel-time differences computed on the basis of the station-to-epicenter distance. For the 11 February 1968 event, the subarray data were also time-shifted on the basis of aligning the P-arrivals by visual inspection of plots of the prefiltered traces. No attempt was made to fit by any other method.

Signal loss, rms noise reduction, and signal-to-noise gain were computed for both teleseismic events. Signal amplitude is defined as half the maximum peak-to-trough amplitude occuring within an 8-second window. Noise amplitude is defined as the root-mean-square value obtained in a 100-second window immediately preceding the P-arrival. The signal-to-noise ratio is defined as the signal amplitude divided by the rms noise amplitude. Gains and losses, in decibels, were computed from the formula:

$$db = 20 \log \left[\frac{value\ on\ the\ phased\ sum}{mean\ value\ of\ the\ input\ channels} \right]$$

Another parameter, called range, was also computed for the noise samples preceding the two teleseismic events. The spectral analysis of the noise sample from each event was performed in the same way as that for the signal-free noise sample described previously. Similarly, plots of the noise power spectra from the unphased sums for the entire array were compared with plots of the average of the spectra from all the subarrays.

RESULTS

Table 1 shows the final results of the analysis of the noise sample from 20 December 1967. The channel identifiers of the subarrays used to form the unphased sums are listed together with the average inter-sensor spacing corresponding to the particular sum. The table also shows the rms noise amplitude reduction produced by the unphased sum and the corresponding $N^{\frac{1}{2}}$ criterion.

The results of the analysis of the noise sample are summarized in Figure 2. Here, the rms noise reduction produced by summing the various combinations of subarrays is shown as a function of the corresponding average inter-sensor spacing and compared with the corresponding $N^{\frac{1}{2}}$ (shown by the dashed lines).

These results, as presented in Figure 2, show that to obtain optimum rms noise reduction, relative to $N^{\frac{1}{2}}$, by summing the array the minimum inter-sensor spacing must be approximately three kilometers.

Figures 3 through 7 show the results of the analysis of the noise power spectra for the various combinations of subarrays used to form the unphased sums. In each figure, the power spectra of the unphased sum of the noise sample was compared with the average of the spectra from all of the subarrays used to form that sum. As these figures show, the spectral shape is essentially the same for both the unphased sum and the average of the individual spectra. The figures also show that, with the exception of the example where the average inter-sensor spacing is only 2.5 km, the unphased sum attenuates the noise at 1 cps, for example, by a factor comparable to $N^{\frac{1}{2}}$.

As noted earlier, the spectral analysis was performed in all cases on data prefiltered to the band 0.7 - 5.0 cps. The Fc filter was used because, as shown in a previous study (Clark, 1968), it reduces the noise to a minimum while preserving

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the first motion and shape. The Fc filter has the disadvantage
of attenuating signal amplitude slightly more than the SDL
filter (0.4-3.0 cps).

Table 2 summarizes the results of the amplitude analysis
of the two teleseismic events under three main headings:
Signal, Noise, and S/N. The amount of signal loss, rms noise
reduction, and signal-to-noise gain produced by beamforming
the array using all 12 elements which were operational at the
time the events were recorded is shown under the corresponding
heading. The source parameters for the two events, which are
taken from P.D.E. cards published by the U.S.C. and G.S., are
given in Table 3.

As shown in Table 2, the signal loss produced by beamforming
the array is less than one db for both events. The rms noise
reduction achieved by forming the beams is equal to the $N^{\frac{1}{2}}$
criterion for both events. The signal-to-noise gain from the
beamsteered array is attenuated one db relative to $N^{\frac{1}{2}}$ for the
two events.

Figures 8 and 9 show the results of the analysis of the
noise power spectra for the two teleseismic events. As
expected, the spectra of the unphased sum is somewhat different
in shape than the average of the input spectra. The figures
also show that, for both events, the noise power at 1 cps is
attenuated by a factor equivalent to $N^{\frac{1}{2}}$.

CONCLUSIONS

This preliminary evaluation of NORSAR short-period data includes an analysis of one signal-free noise sample and the records from two teleseismic events. The following conclusions are based on the results of this study:

1. The minimum inter-sensor required to produce an optimum rms noise reduction, relative to $N^{\frac{1}{2}}$, by prefiltering and summing the array outputs is approximately three kilometers.

2. A signal loss of less than one db is produced in beamforming the array by time-shifting the subarray data using only computed travel-time differences. Part of this signal loss results from using the Fc filter. The remainder of the signal loss is attributed to small misalignment of the P wave and to differences in wave form across the array.

3. In all cases where the average inter-sensor spacing is greater than three kilometers, the rms noise reduction is equivalent to the $N^{\frac{1}{2}}$ criterion. This same noise reduction factor is shown by the power spectra at 1 cps.

4. A 3-to-1 ratio of Range-to-RMS is obtained in all cases for a 100 second noise sample.

5. The signal-to-noise ratio produced by the beamformed array is attenuated one db relative to $N^{\frac{1}{2}}$.

RECOMMENDATIONS

Additional studies which are suggested by the results of this preliminary evaluation of NORSAR include:

1. A study to compile observed travel-time anomalies which can be used in conjunction with cross-correlations to reduce the signal loss in beamforming the array.

2. The design and evaluation of a band-pass filter which will retain the noise reduction characteristics of the Fc filter while reducing the signal loss of the present filter.

3. An evaluation of the detection and identification capabilities of NORSAR as compared to other arrays.

REFERENCE

Clark, D.M., 1968, "Preliminary Beamforming Study of the TFO-37 Array", Report No. 216, Seismic Data Laboratory, Teledyne Inc., Alexandria, Virginia.

TABLE 1

NORSAR NOISE SAMPLE - DATA PREFILTERED 0.7 - 5.0 CPS (Fc)

DATE: 29 Dec 1967 (363)   Seis. No. 14901
START TIME OF DATA SAMPLE: 06 30 18.6 Z
LENGTH OF DATA SAMPLE: 3 min. (3600 points, 20 PPS)

CHANNELS USED	(N)	Average Inter-Sensor Spacing km	mu		db	mu		db	MEAN RANGE RMS	-20log√N
			MEAN RMS	U-SUM	Σ/ MEAN RMS	MEAN RANGE	U-SUM	Σ/ MEAN RANGE		
1OY,1A2,1A3,1C1,1C2,1C3, 1D1,1D2,1D3,1F1,1F4	11	7.6	3.56	1.125	-10.0	10.54	3.59	-9.3	2.96	-10.4
1OY,1F1,1F4	3	2.5	3.55	2.272	- 3.9	11.01	7.55	-3.3	3.09	-4.8
1C3,1D1,1D2	3	3.4	3.38	1.878	- 5.1	9.83	5.81	-4.6	2.93	-4.8
1C1,1C2,1D1	3	4.9	3.50	1.967	- 5.0	10.26	5.18	-5.9	2.94	-4.8
1C2,1D3,1F4	3	8.7	3.58	1.969	- 5.2	10.82	6.26	-4.8	3.01	-4.9

TABLE 2

NORSAR P-WAVE AMPLITUDES FOR DATA PREFILTERED 0.7 - 5.0 CPS (Fc)

EVENT	DATE	N¹⁄² db	SIGNAL mµ MEAN	SIGNAL mµ P-SUM	SIGNAL db P-SUM/MEAN	NOISE mµ MEAN RMS	NOISE mµ P-SUM RMS	NOISE db P-SUM MEAN/RMS	NOISE mµ MEAN RANGE	NOISE mµ P-SUM RANGE	NOISE db P-SUM MEAN RANGE	NOISE db MEAN RANGE RMS	S/N S/RANGE MEAN	S/N S/RANGE P-SUM	S/N S/RANGE db P-SUM/MEAN	S/N S/RMS MEAN	S/N S/RMS P-SUM	S/N S/RMS db P-SUM/MEAN	
Kuril Is.	04 Feb 68	11	12.45	116.7	-0.6	2.34	0.65	-11	7.11	1.97	-11	3.1	17.8	59.2	+10	53.6	179.0	+10	N=12
Tibet	11 Feb 68	11	36.9	35.0	-0.5	2.09	0.62	-11	6.33	2.23	- 9	3.0	5.9	15.7	+ 9	17.6	56.7	+10	N=12

TABLE 3

BULLETIN STATISTICS FOR TWO TELESEISMIC EVENTS

| EVENT | DATE | ORIGIN TIME | LOCATION | | DISTANCE FROM 10Y | | DEPTH KM | BACK AZIMUTH (10Y) | CAL. DATE | USC&GS M | SEIS. NO. |
			LAT	LONG	DEG	KM					
Kuril Is.	04 FEB 68	11 00 50.12	43.0N	147.1E	70.205	7806.4	33	32.5	11 FEB 68 (20 05 55- 20 06 55)	5.5	14961
Tibet	11 FEB 68	20 38 29.47	34.2N	78.6E	50.226	5584.9	44	90.2	11 FEB 68 (20 05 55 - 20 06 55)	5.1	14962
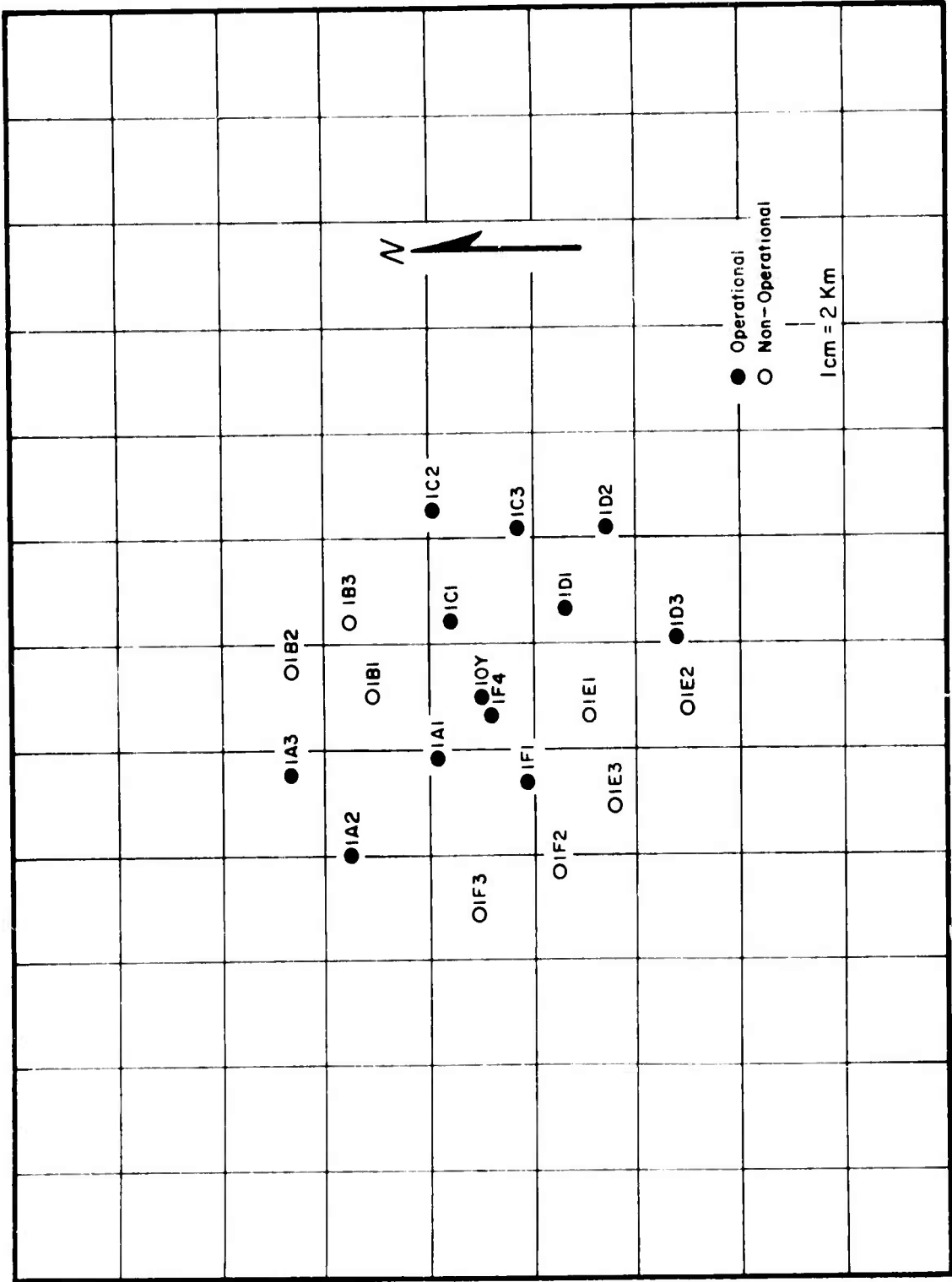
Figure 1. NORSAR SP2 Array Configuration
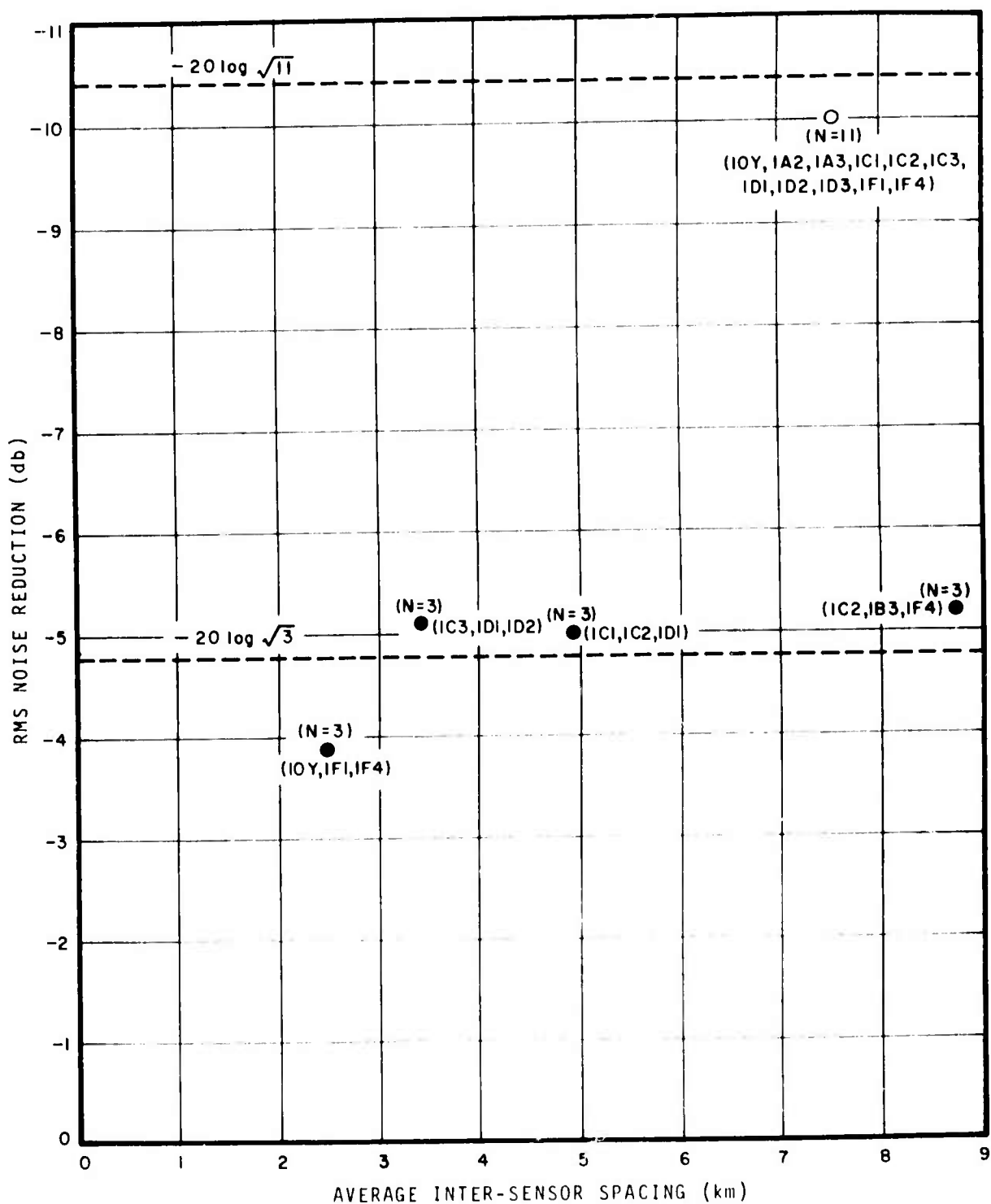
Figure 2.   RMS Noise Reduction by summing
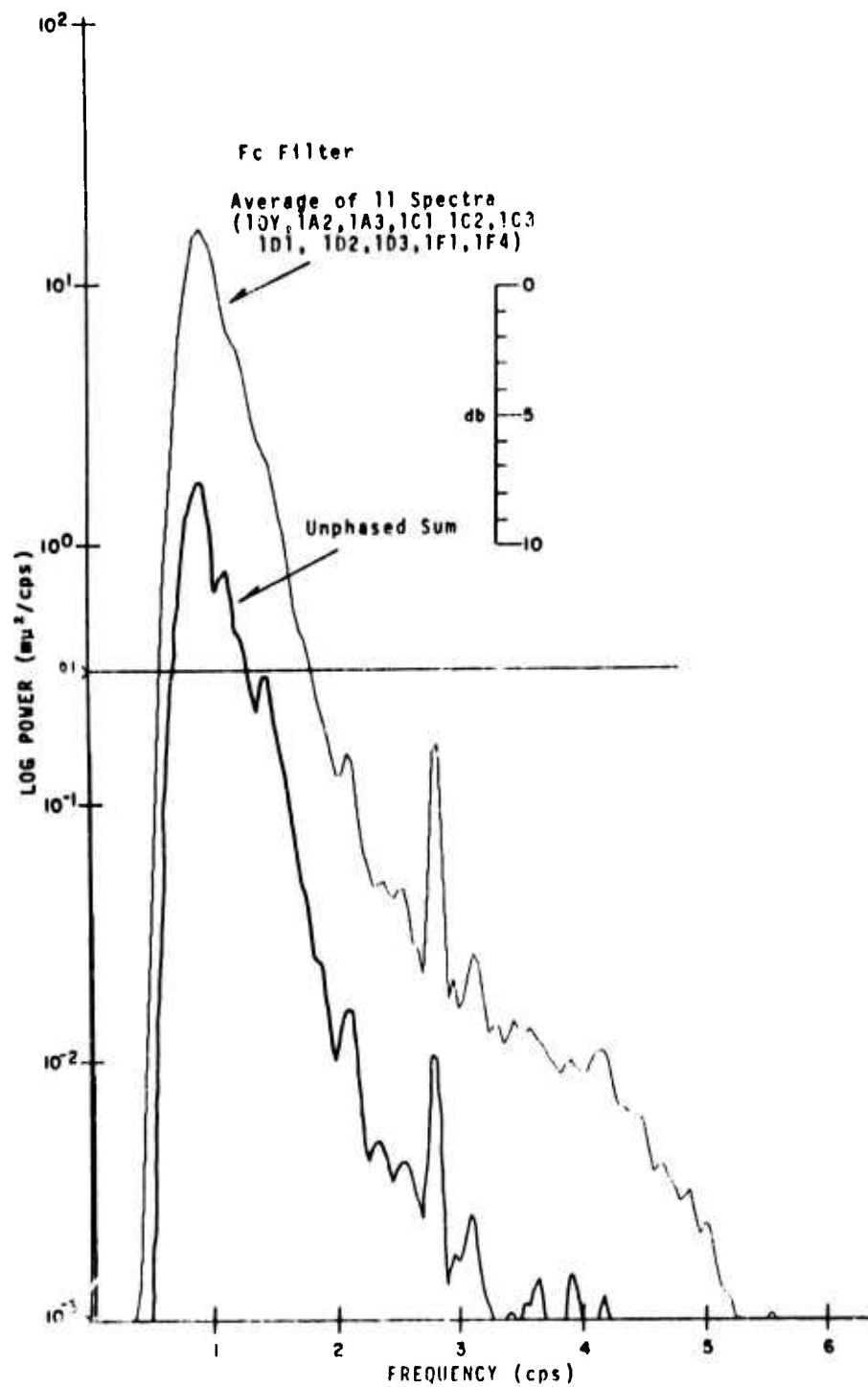various combinations of NORSAR
Elements

Figure 3. Noise Power Spectra 29 Dec 1967.
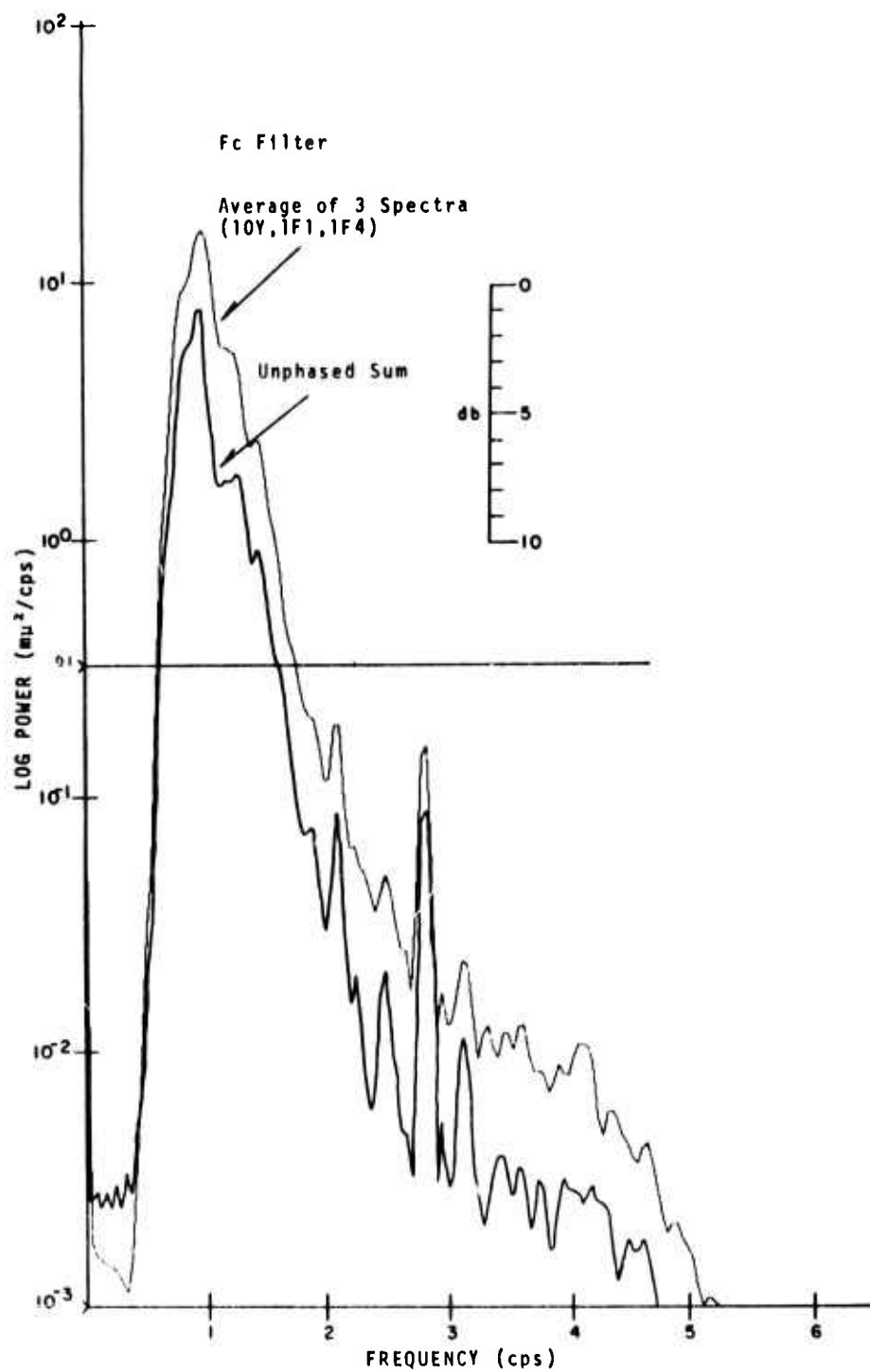Average Inter-Sensor Spacing = 7.6km

Figure 4. Noise Power Spectra 29 Dec 1967.
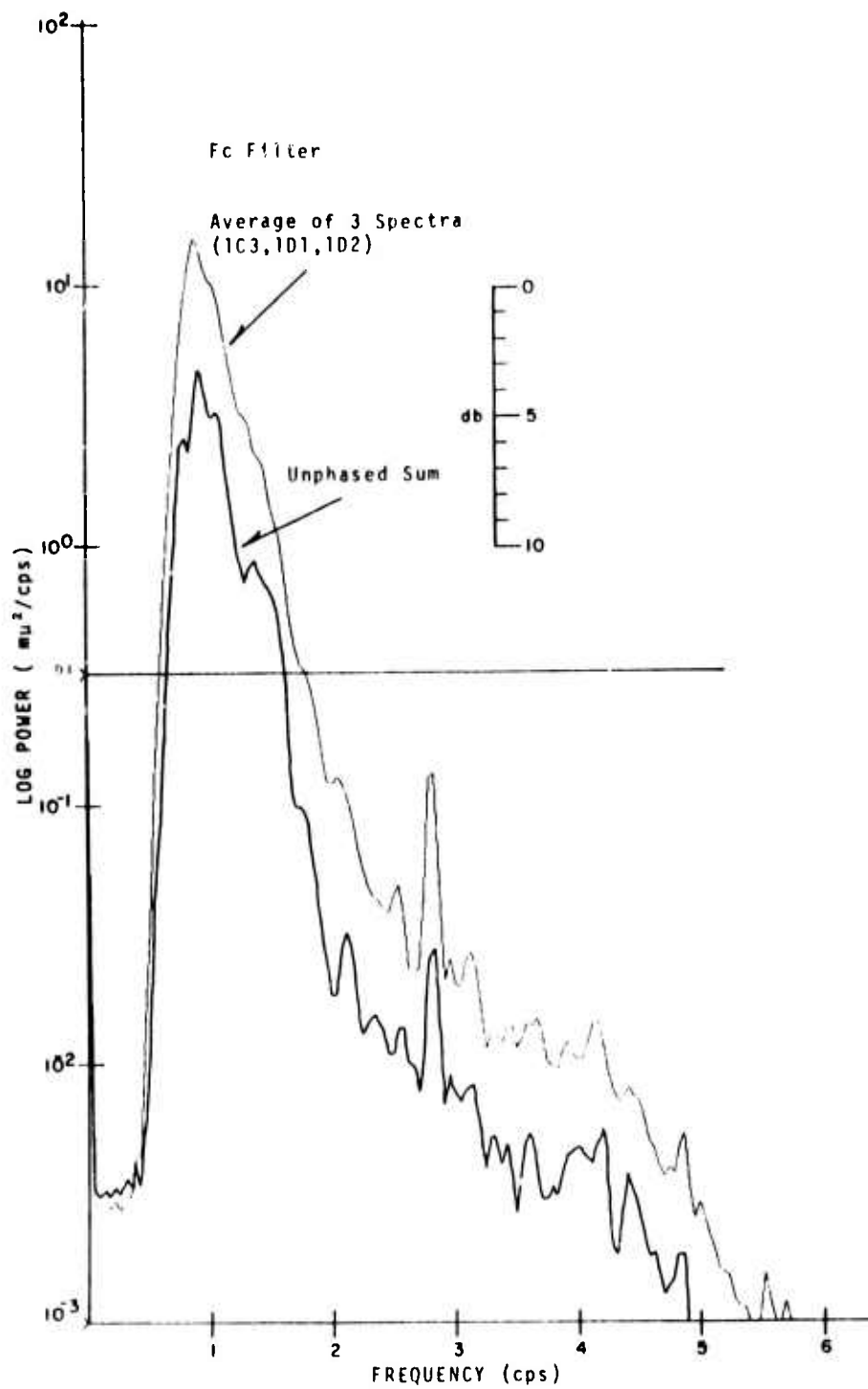Average Inter-Sensor Spacing =2.5km

Figure 5. Noise Power Spectra 29 Dec 1967.
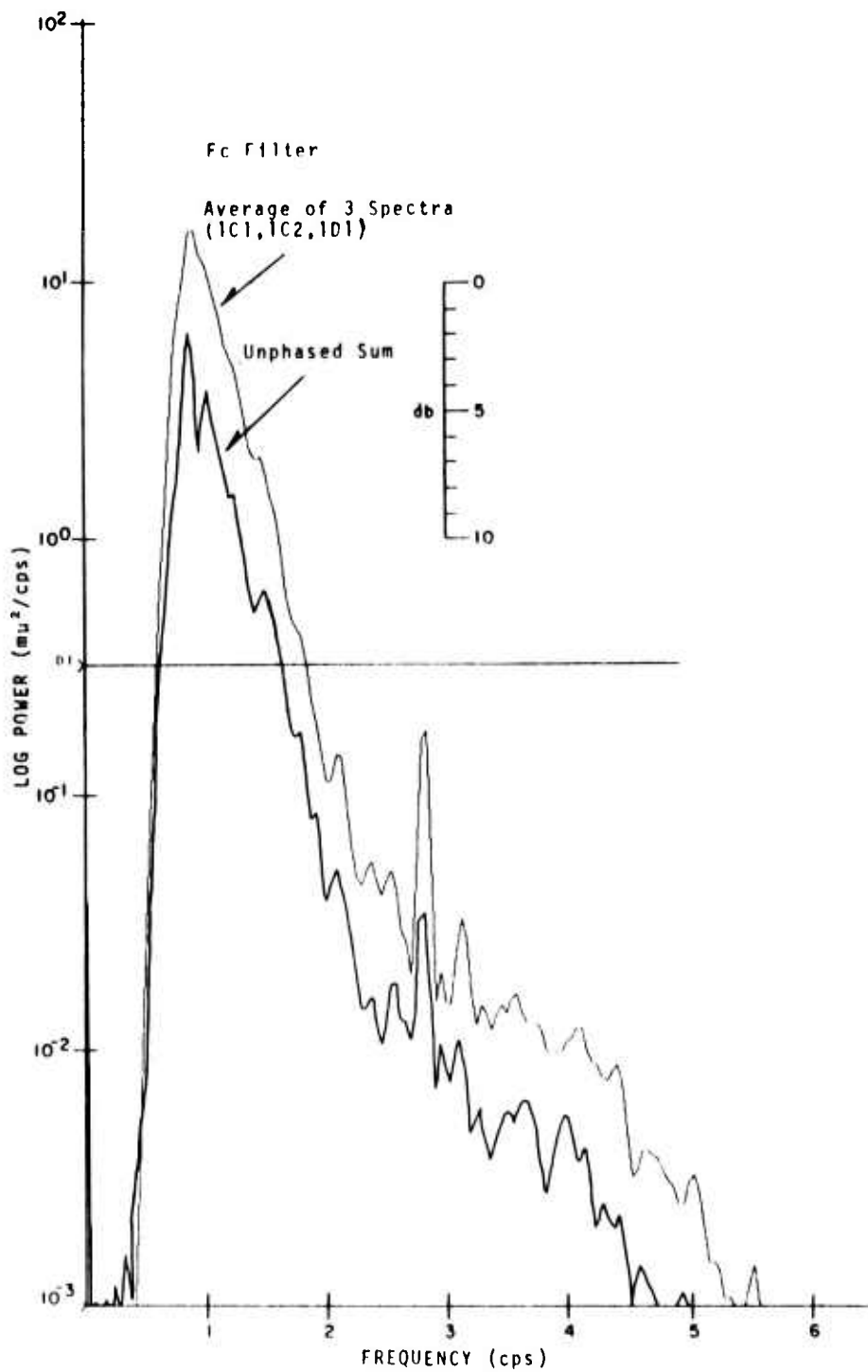Average Inter-Sensor Spacing = 3.4km

Figure 6. Noise Power Spectra 29 Dec 1967.
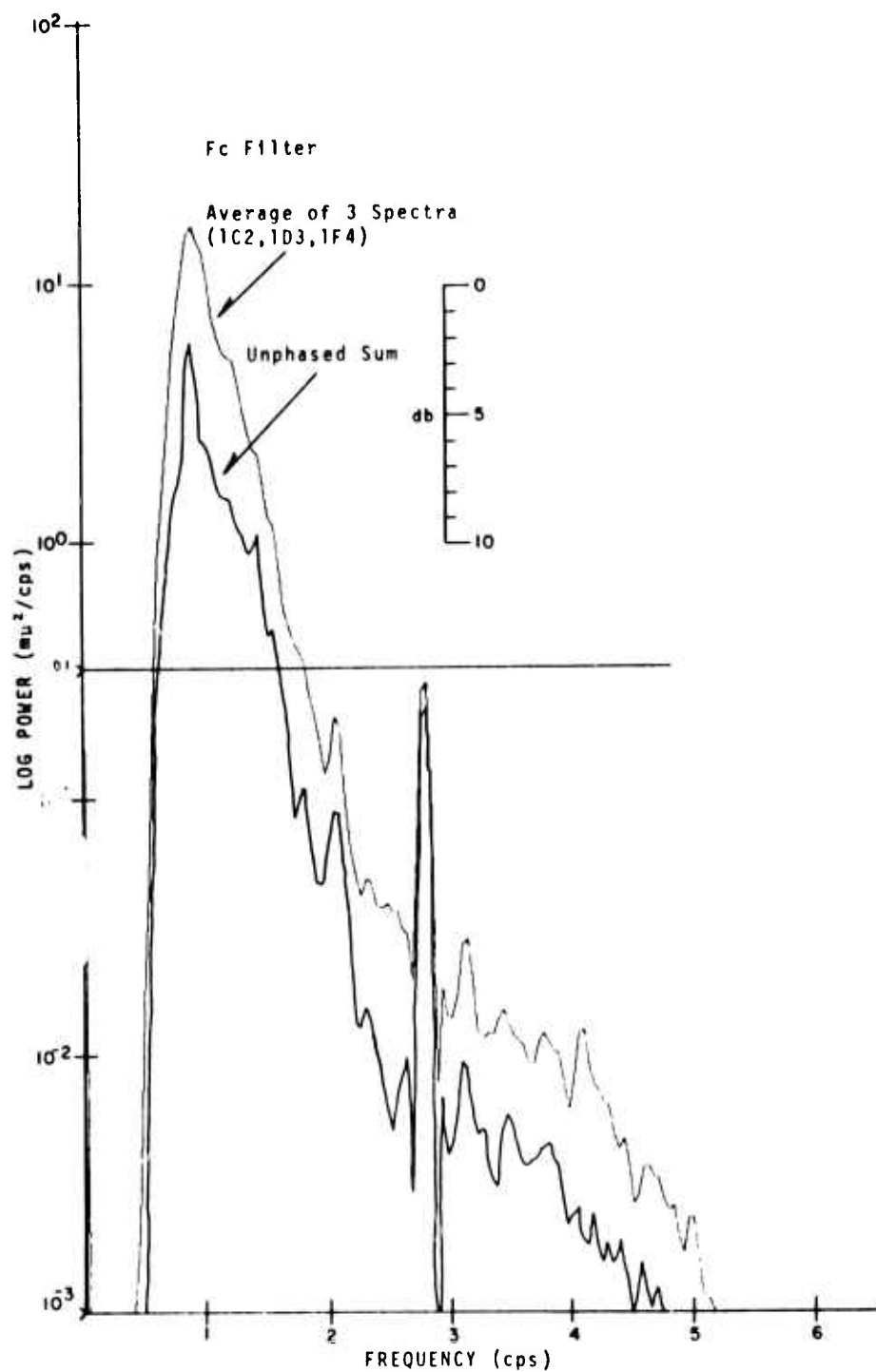Average Inter-Sensor Spacing = 4.9km

Figure 7.   Noise Power Spectra 29 Dec 1967.
Average Inter-Sensor Spacing = 8.7km
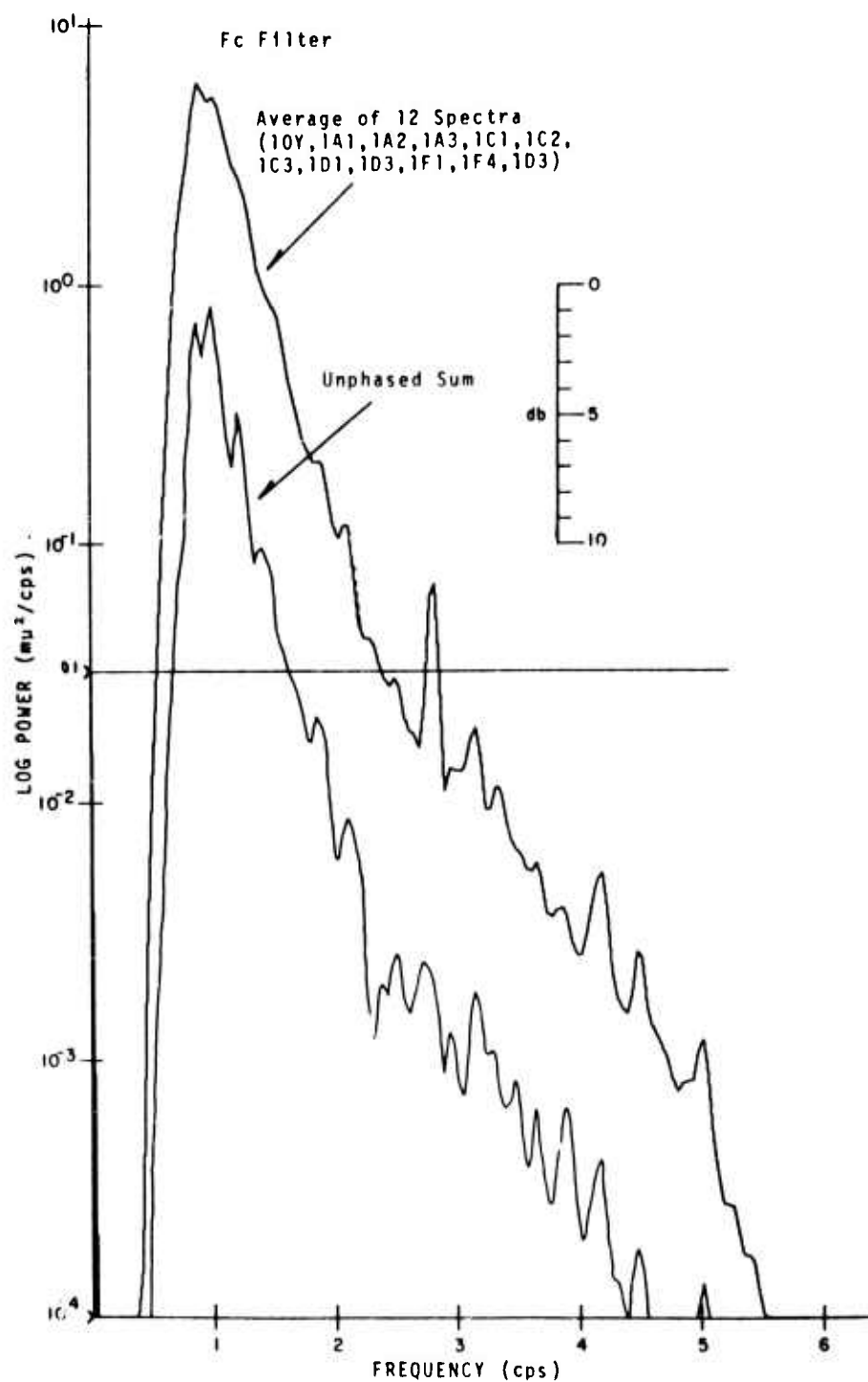
Figure 8.   Noise Power Spectra, Kuril Island,
            4 Feb 1968. Average Inter-Sensor
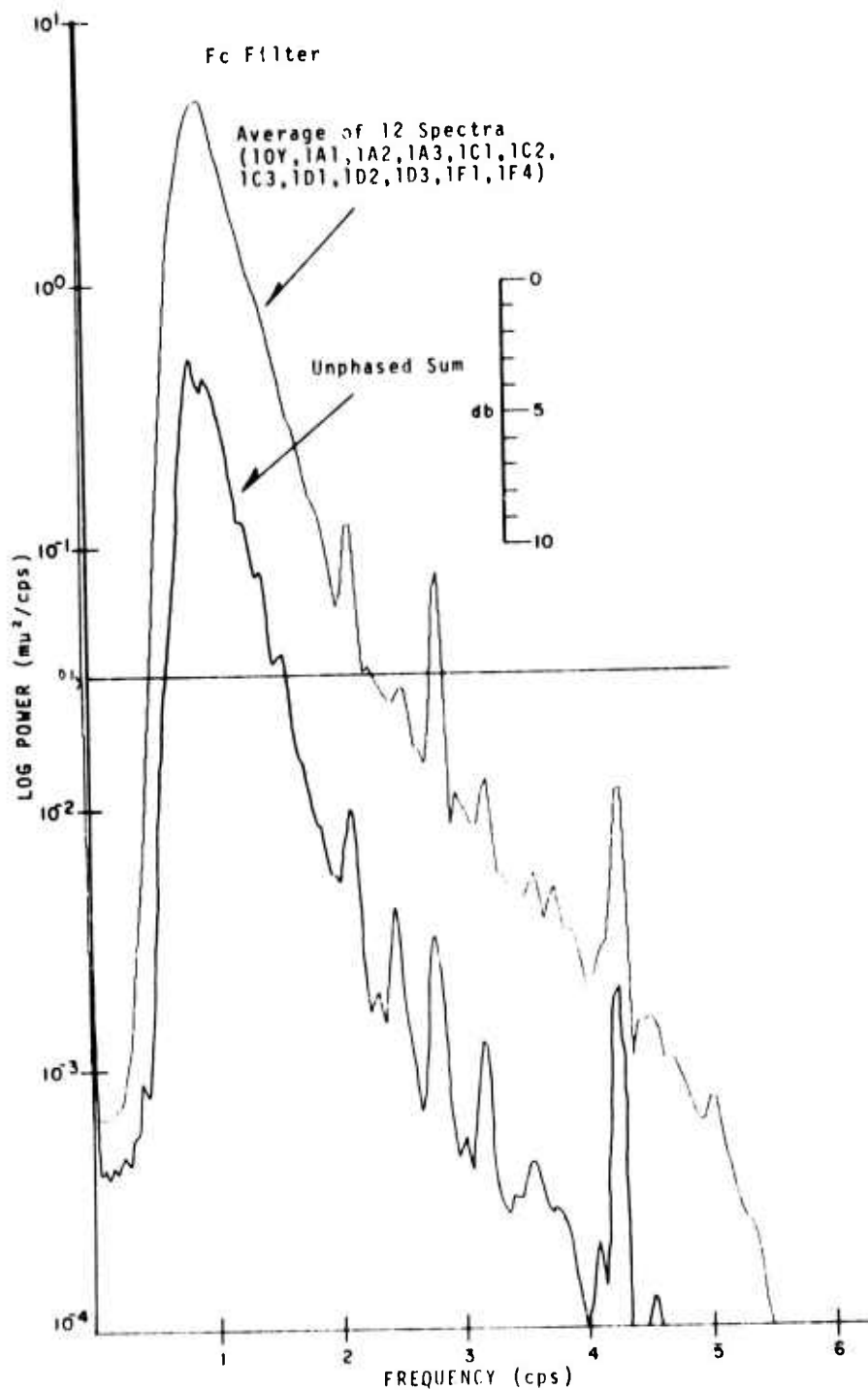   Spacing = 7.4 km

Figure 9. Noise Power Spectra, Tibet, 11 Feb
1968. Average Inter-Sensor Space-
ing = 7.4 km

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